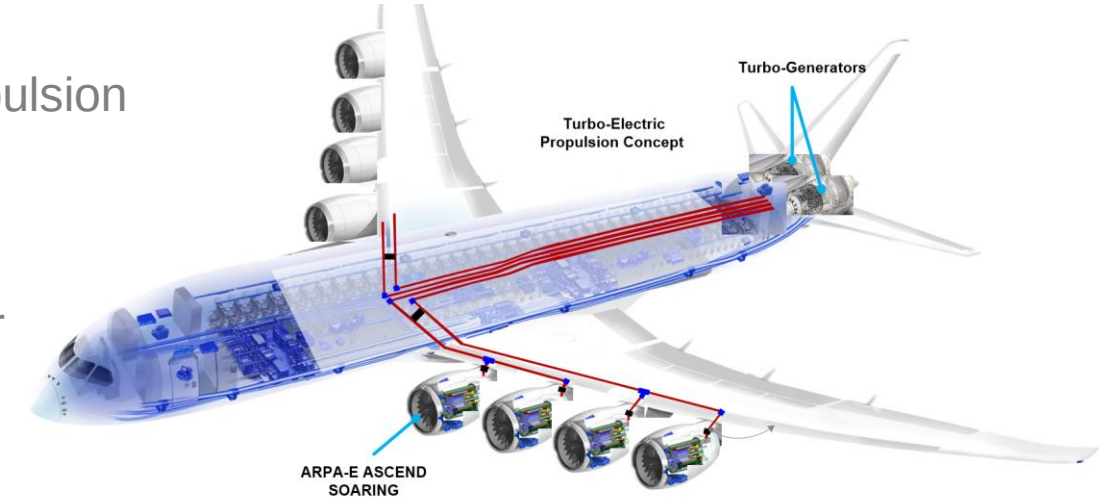
Superconducting Motor and Cryo-Cooled Inverter Engine: SOARING

PI: Parag Kshirsagar, Raytheon Technologies Research Center

Project Vision

Disrupting Multi-MW Class Aircraft Propulsion through extreme power density:

- Fully Superconducting AC motor
- Cryocooled motor drive and
- Adaptive Magnetocaloric Cryo-cooler



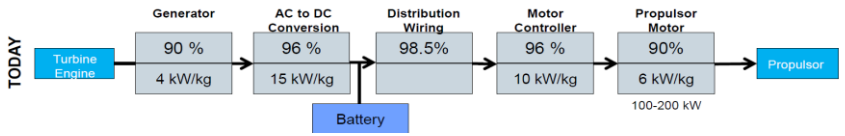
REEACH / ASCEND / CABLES
Annual Program Review Meeting
June 28-30, 2022

Raytheon Technologies · Pacific Northwest National Laboratory · The University of Tennessee Knoxville · Hyper Tech · The Ohio State University

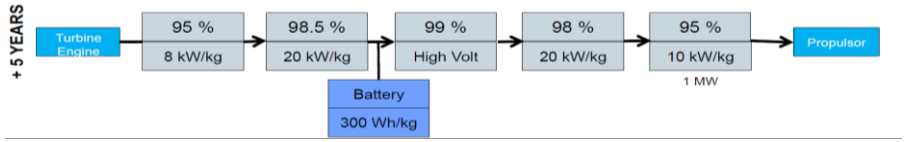
Background: 20MW Electrified Aircraft

Electric Propulsion System

SOA Today Sp =1.5 kW/kg, ηelec= 73%



+ 5 Years Sp =2.8 kW/kg, ηelec= 86%

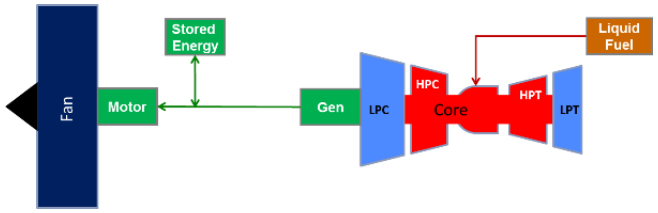


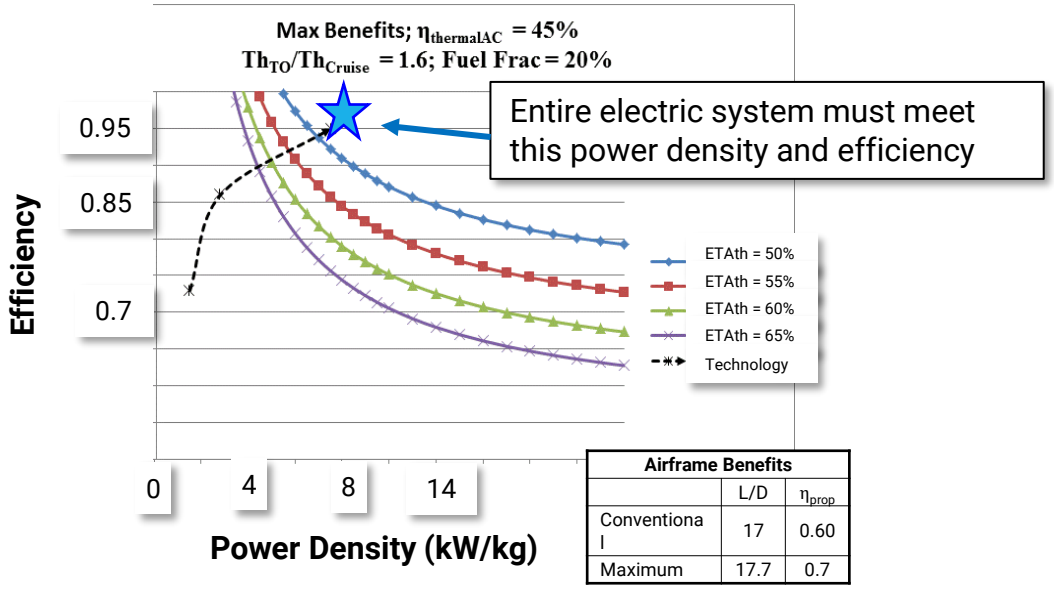
+10 Years Power Pillar Sp =7.5 kW/kg, ηelec= 95%

Efficiency of components ⩾ 99%

Power density of components: X3 – X4 over SOA Today

20MW Series Turbo-electric





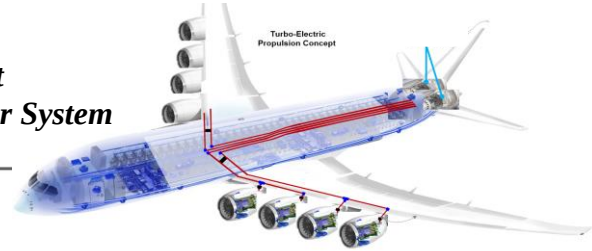
Airframe Benefits		
	L/D	η_{prop}
Conventional	17	0.60
Maximum	17.7	0.7

- Electric propulsion technology to achieve fuel savings for given configuration
  - Electric System Efficiency and Specific Power
  - Breakeven curves: fuel weight reduction equals weight of electric drive system
  - Above curves, net benefit

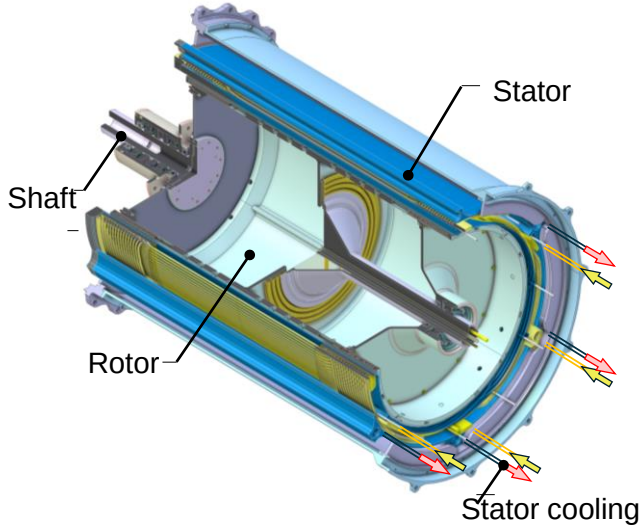
P. Kshirsagar et.al. AIAA 2020, Adapted from Jansen et al. 2015, 2017.

SOARING Overview

20MW Conceptual Aircraft
Cryofuel (Bio-LNG) Enabled Power System

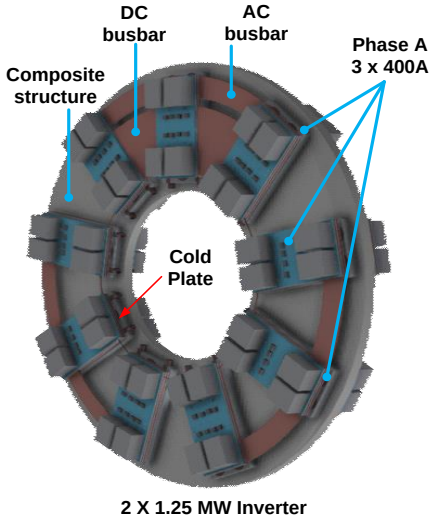


Fully Superconducting Motor (ACSYM) Direct Drive (no-gear)



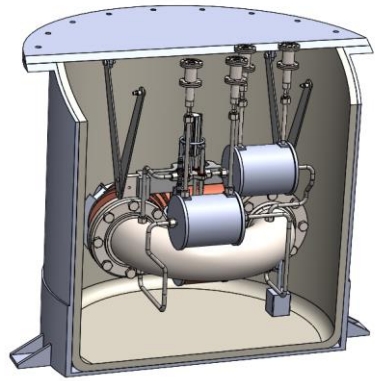
2.5MW, 5000rpm, 20K
Efficiency > 99%

Motor Drive (CROWN)



2.5MW, 120K
Efficiency > 99%

Magnetocaloric cryocooler (AMAC)



120K to 20K (AMAC)
COP target 0.6 (3x over SOA),
Power density Target 4W/kg (3x to 5x over SOA)

Phase-1: Conceptual Design

Phase-1: 40W Demonstration

SOARING: Team Organization

Phase-1

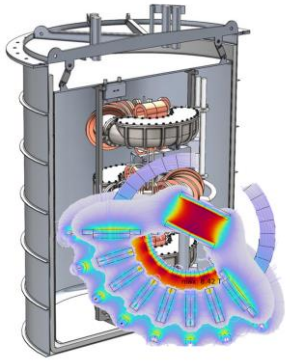
Raytheon Technologies

RTRC — Raytheon Technologies Research Center

KGPS

EMVIONIC

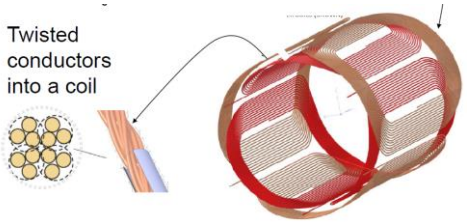
Pacific Northwest National Laboratory

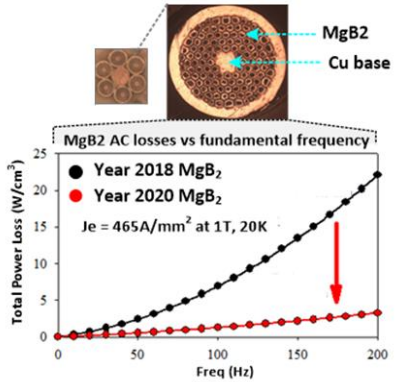


80K to 20K 40W AMAC Demo

Hyper Tech

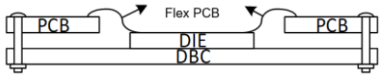
The Ohio State University

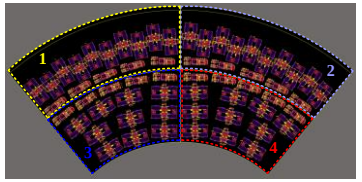




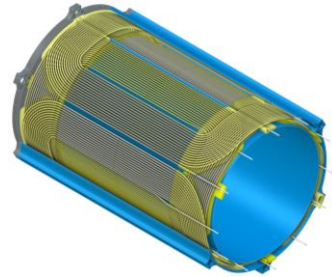
Concept design of superconducting wires for stator and rotor

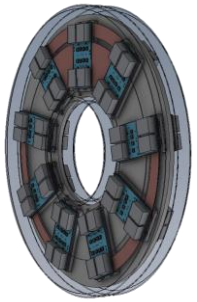
The University of Tennessee Knoxville





Concept design package of GaN based cryocooled motor drive



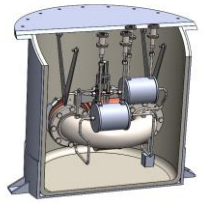


Concept design integration of motor, motor-drive and AMAC

SOARING: TMS Performance +Motor + Power Electronics

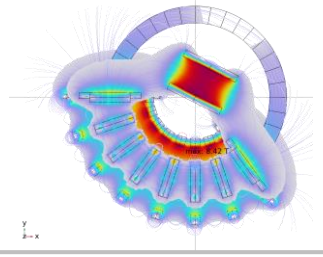
TMS-AMAC

Phase-1 Demo



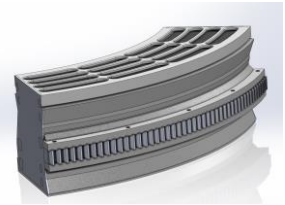
40 W 120K to 20K (AMAC)
COP target 0.6 (3x over SOA),
Power density 4W/kg (3x to 5x over SOA)

High Field Magnet Design



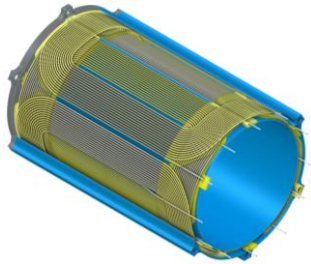
Rotary Seal Testing

Rotating regenerator frame design



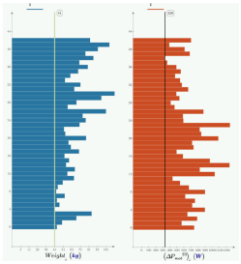
MOTOR

Phase-1 Concept Design



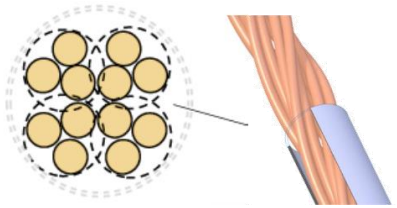
Superconducting Motor
Take off Efficiency > 99%
Direct Drive (no-gearbox)

Design tradeoffs

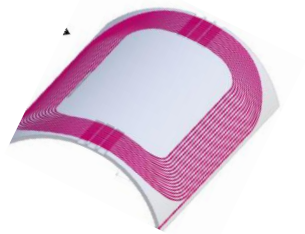


Weight ***Losses***

AC Superconductors Manufacturing, packaging, cooling, and loss estimation



Wind and react manufacturing, direct cooling channels

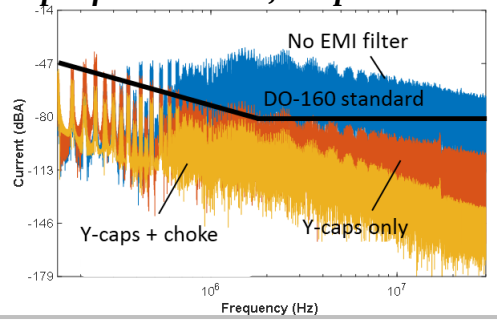


MOTOR DRIVE

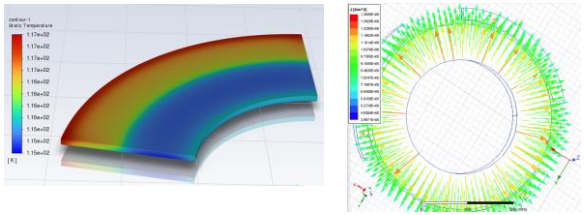
Phase-1 Concept Design

Cryo Motor Drive
Takeoff Efficiency > 99%

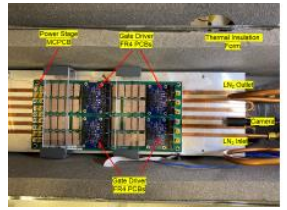
Input filter DO-160, Output THD < 1%



Power Module, Busbar, Capacitor Cooling

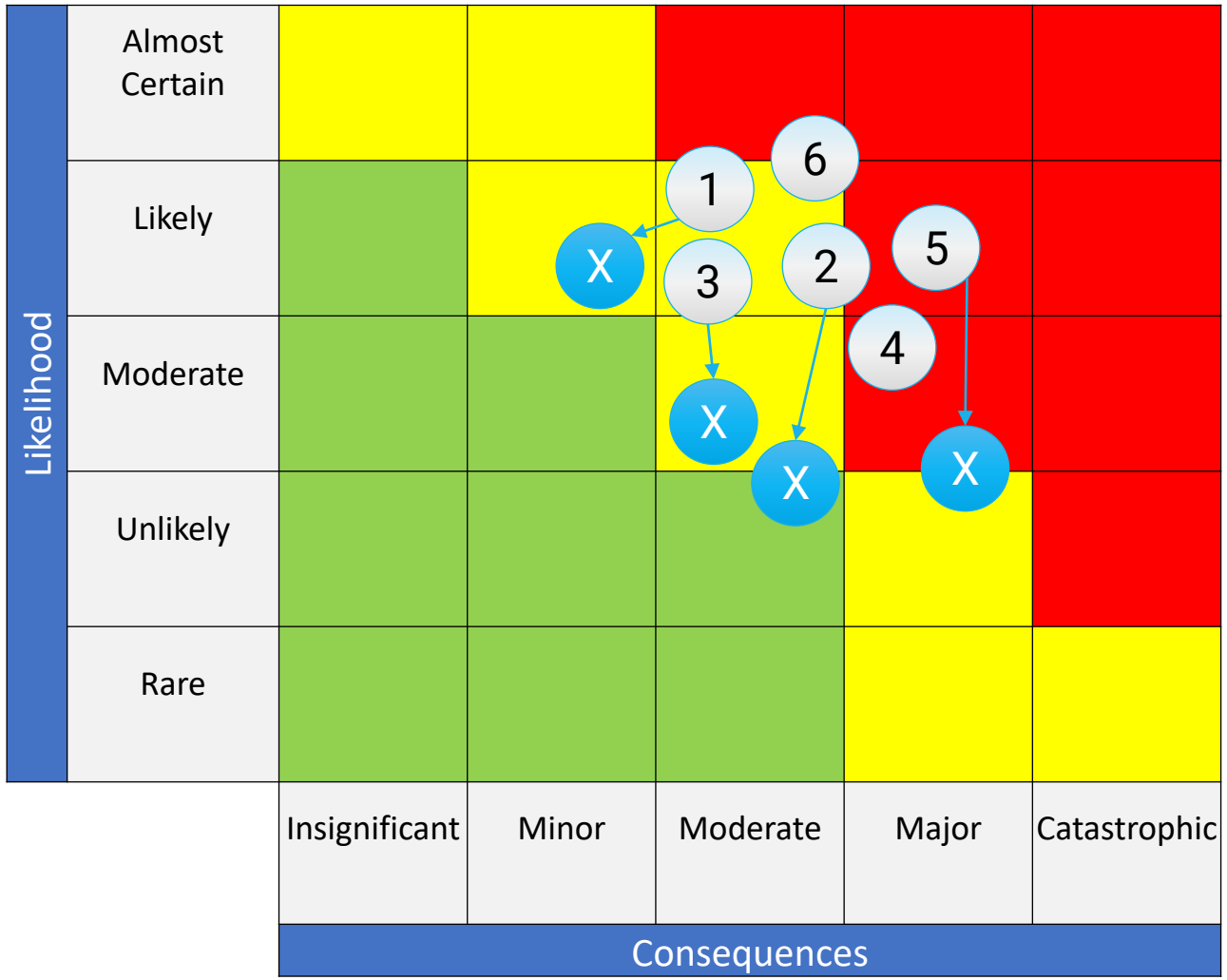


Low power Cryogenic converter testing



SOARING Risk Update

Risk	#	Trend
Manufacturing, support and cooling of the SC coils, AC Losses	1	↓
Effectiveness of the seals at cryo temperatures	2	↓
High lead losses between motor and drive	3	↓
Weight of AMAC	4	▬
Low cost high strength DC magnets for AMAC	5	↓
Cost of the SOARING system	6	▬



Technology-to-Market Approach

Superconducting motors scales better at higher power levels

Notional timeline with 20K GHe cooling - Does not include Bio-LNG or LH2 Hx, etc.

TRL 0 — TRL 2 — TRL 3 — TRL 4 — Proof of Concept 3MW Ground Demo — Turbo-electric

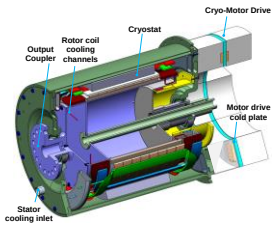
2019-2020	2021	2023	2024	2025	2026	2027	2028	2029

ARPA-E ASCEND Cryocooler, Motor and Motor Drive **Scaled (260kW)** Demo

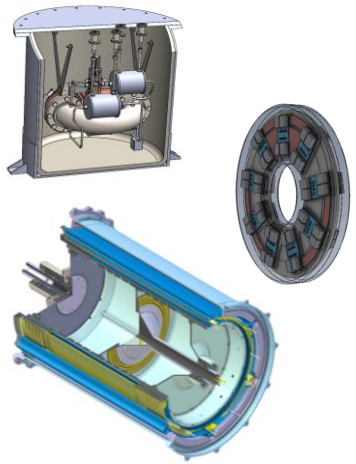
Proposal	Phase-1	**Phase-2**

Engine Integration (need additional resources)

Partner with Govt Agencies, Airframer and Airliners on demonstrating power generation, integration, and safety

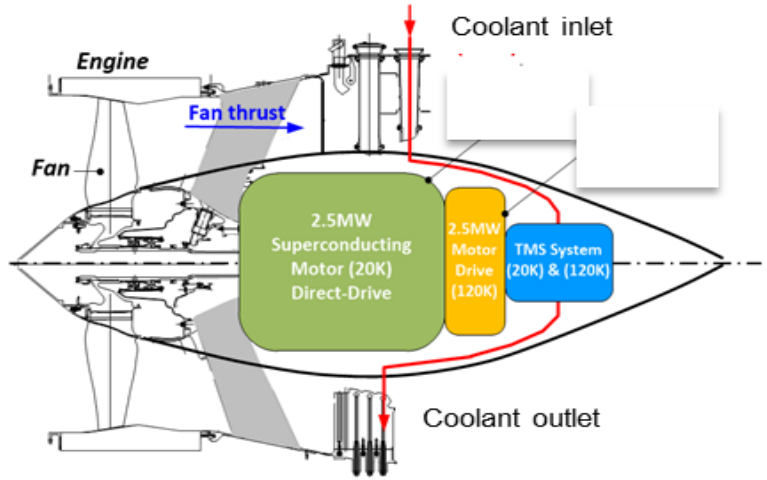


20K
3MW SC Motor and Drive



20K
3MW SC Motor, Drive and Cryocooler – Detailed Concept design

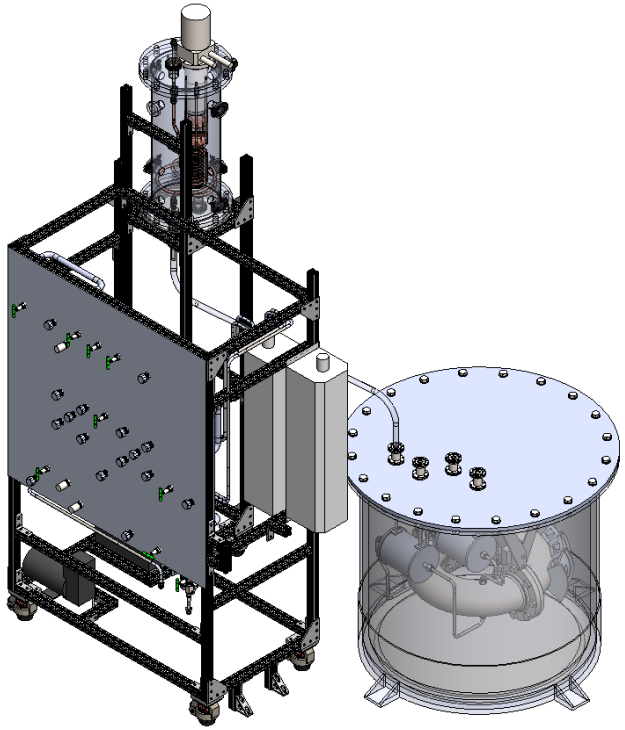
Test Demo Option



Looking Ahead – What is anticipated for an Eventual Phase II?

- *Phase I*
  - *Motor: Proof of concept stator coil coupon*
  - *AMAC Demo*
- *Phase II.*
  - *Preliminary design of motor, motor drive and TMS*
  - *Detailed design of motor, motor drive and TMS*
  - *Sub-component integration and scaled demonstration*
- *T2M during the eventual Phase II.*
  - *Aerospace Applications: Collaboration with Propulsion partner, Airframer, and Airliner*
  - *Liquid hydrogen applications (Liquefier manufacturers)*
  - *Non-Aerospace Applications: Transportation Vehicles, and Space Applications*

AMAC Demonstration setup at PNNL



Q & A

https://arpa-e.energy.gov